PERFORMANCE EVALUATION OF SOLAR AIR HEATERS WITH SINGLE AND DOUBLE PASSESS

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A Project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JANUARY 2012

To my beloved mother and father

&

Siblings

ACKNOWLEDGEMENTS

I would like to express thanks to Allah, with his blessing in fulfilling my thesis and sustaining me throughout this research.

I would also like to express my sincere appreciation to my supervisor, Assoc. Prof. Dr. Mazlan Abdul Wahid, for his invaluable guidance, advices and critics. Further I would like to appreciate my Co.supervisor, Prof. Amer Nordin Darus for his encouragement, guidance and patience.

I would like to thank my family members, for supporting and encouraging me to pursue this degree, and the very genuine appreciation goes to my father and mother for their immensurable support and love.

My gratitude also goes to all my friends who helped me in preparing this thesis.

ABSTRACT

Numbers of studies have been carried out on the performance analysis of single and double pass solar air heaters. These studies include the design of solar air heater, heat transfer enhancement , flow phenomenon and pressure drop in duct. In this thesis, mathematical modeling based on energy analysis for three different configurations of solar air heater namely single pass with one and two covers and double pass have been developed. It was shown that for each collector the energy balance equations of the components of the collector , at quasi steady state, providing a 3×3 non linear differential equation. A code was written to solve the equations by means of finite difference approach using MATLAB software. The effect of the most significant ambient and design parameters such as ambient temperature, mass flow rate and channel height on the performance of each model was investigated and compared to each other. It was shown that the thermal performance of the double cover single pass air heater in terms of fluid outlet temperature and thermal efficiency is higher than single cover one and this amount is even higher in case of a double pass air heater. It was observed also that the performance of solar air heater increases as the height of the lower glass cover to the absorber decreases. This fact was illustrated by introducing a factor of efficiency difference referred to the efficiency of the collector of a special channel height ratio to the one with the same height of the two channels. Finally the numerical simulation was successfully validated with the published results. Computed parameters such as efficiency, outlet temperature and Nusselt number was in good agreement with the existing experimental and numerical data.

ABSTRAK

Di dalam kajian yang lalu analisis terhadap pemanas air solar satu dan dua pass telah banyak dijalankan. Kajian tersebut termasuklah mereka bentak pemanas air solar, analisis pemirdahan haba, fenomena aliran dan analisa kejatuhan tekanan dalam sesalur.

Dalam thesis ini, model matematik yang berasaskan analisis tenaga untuk tiga jenis pemanas air solar telah dibentuk. Dalam kajian ini, telah dibuktikan bahawa pada setiap pemanas, analisis. Menghasilkan 3×3 persamaan kebezaan yang tidak linear. Oleh itu, satu program menggunakan MATLAB telah digunakan untuk menyelesaikan persamaan tersebut. Dalam kajian ini, didapati bahawa suhu bendalir yang keluar dari pemanas air dua ‘pass’ adalah lebih tinggi daripada pemanas air satu ‘pass’. Juga terdapat disimpulkan bahawa semakin dekat penutup gelas dengan piring absorber, semakin baik sesebuah pemanas air itu. kajian menunjukkan bahawa analisis data yang dijalankan dapat dibuktikan menyamai dengan keputusan ujikaji yang terdapat dalam kajian lalu yang telah diterbitkan. Bebesapa parameter yang telah diperolehi secasa simulasi seperti keukapan, suhn kelnarar dan nombor Nusselt didapati bersamaan dengan keputusan yang telah diperolehi secara ujikaji oleh penyelidik terdahulu.

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LIST OF SYMBOLS

English Symbols			UNIT
A	-	Collector area	$[\mathrm{m}^2]$
A_c	-	Collector area	$[m^2]$
C_P	-	Specific heat	[J/kg K]
D_h	-	Hydraulic diameter	[m]
G	-	Mass flow rate per unit collector area	$[\mathrm{kg/s/m^2}]$
h	-	Convection heat transfer coefficient	$[\mathrm{W/m^2/K}]$
h_r	-	Radiation heat transfer coefficient	$[\mathrm{W/m^2/K}]$
h_{fp}	-	Heat transfer coefficient between absorber and fluid	$[\mathrm{W/m^2/K}]$
h_b	-	Heat transfer coefficient between back plate and fluid	$[\mathrm{W/m^2/K}]$
h_a	-	Heat transfer coefficient between ambient and the glass	$[\mathrm{W/m^2/K}]$
h_{fc}	-	Heat transfer coefficient between the glass cover and working fluid,	
I	-	solar intensity	[W/m2]
L	-	Collector length	[m]
H	-	Collector height	[m]
W	-	Collector width	[m]
$\dot{m}$	-	Mass flow rate	[kg/s]
Nu	-	Nusselt number	[-]
Pr	-	Prandtl number	[-]
Q_u	-	Useful thermal power	[W]
Re	-	Reynolds number	[-]
T_a	-	Ambient temperature	[K]
T_c	-	Transparent cover temperature	[K]
T_f	-	Fluid temperature	[K]
T_p	-	back plate temperature	[K]
T_s	-	Selective absorber temperature	[K]
T_{ap}	-	Absorber temperature	[K]

T_b	-	Temperature of absorber channel back plate	[K]
U_b	-	Bottom loss coefficient	[W/m2/K]
U_L	-	Overall loss coefficient	[W/m2/K]
U_b	-	Collector bottom and edge loss coefficient	[W/m2/K]
U_t	-	Collector top loss coefficient	[W/m2/K]
V_a	-	Wind speed	[m/s]
T_a	-	Ambient temperature	[K]
T_f	-	Fluid temperature	[K]
U_L	-	Overall collector heat loss coefficient	[-]

Greek Letters

K	-	Thermal conductivity	[W/m/K]
ρ_f	-	Fluid density	[kg/m3]
α_p	-	Absorptance of absorber plate	[-]
ε_p	-	Emittance of absorber plate	[-]
η	-	Collector thermal efficiency	[-]
α_c	-	Absorptivity of glass cover	[-]
τ_c	-	Transmittance of cover	[-]

CHAPTER 1

INTRODUCTION

1.1 Introduction

Solar energy is the world's most plentiful enduring source of energy. According to Sopian *et al*. (1999) the amount of solar energy intercepted by Earth is 170 trillion kW, 30% of this amount is reflected to space, 47% is converted to low temperature heat and reradiated to space, and 23% powers the evaporation/precipitation cycle of the biosphere, where less than 0.5% of this energy is presented in the kinetic energy of wind and waves and in the photosynthesis storage in plants. Compared to fossil fuels solar energy is non- polluting, has no moving parts to breakdown, and does not require much maintenance (Nidal, 2003).

In comparison with solar water heaters, solar air heaters have received relatively less investigation and have resulted in fewer commercial products. However they are employed in many applications requiring low to moderate temperatures (below 80 degrees centigrade), such as crop drying and space heating, thus, design optimization is crucial. The development of a cost effective and efficient solar collector is essential to the system's overall feasibility (Summers et al., 2011).

Solar collectors are employed to convert incident solar radiation into thermal energy at the absorbing surface, and transferring this energy to a fluid (commonly water or air) flowing through the collector (Naphon, 2003). Solar air heater uses air as the transporting fluid. It is extensively used in industrial and agricultural applications without the optical concentration. The solar air heater has minimal use of materials and the direct use of air as the working substance reduces the number of required system components, resulting in simpler design and less maintenance together with less corrosion and leakage problems compared to liquid solar systems (Ammari, 2003; Yeh et al., 1999; Mohamed, 1997). On the other hand, air type solar collectors have two inherent disadvantages i.e. low thermal capacity of air and low absorber to air heat transfer coefficient (Karim and Hawlader, 2004). Consequently several studies to determine the thermal performance of solar air heaters have been conducted, theoretically and/or experimentally, and different modifications are suggested and applied to improve the heat transfer coefficient between the absorber plate and air (Ong, 1995; Metwally et al., 1997; Yeh et al., 2002; Froson et al., 2003).

A simple solar collector consists of a black painted metallic absorber covered with one or two glass cover panes. The performance of a solar heater depends on the losses from the collector surfaces. The use of more than one cover improves the efficiency of the collector at higher collector temperatures but, simultaneously reduces the quantity of incoming solar radiation on the absorber because of higher reflective losses (DAS. S. K., 1991).

The glazing acts to prevent heat losses from the panel to the environment via convection and radiation, to prevent mechanical damage to the absorber's components and to act as an easy-to-clean surface. It is vital, therefore, that incoming solar radiation (in the near infrared) is allowed to pass through the glazing relatively unhindered, but that radiative thermal losses (in the far infrared) are blocked (i.e. the green house effect). The solar radiation transmitted through the glazing propagates onto the absorber plate. The absorber plate must absorb an optimum amount of solar radiation whilst minimizing thermal re-radiation. Heat is removed from the absorber plate by means of flow of air. The lower specific heat capacity and density of air does, however, necessitate the use of higher flow rates to achieve sufficient heat transfer, and this may lead to excessive friction losses (Dorfling, 2010).

The main drawback of an air heater is that the heat transfer coefficient between the absorber plate and the airstream is low, which results in a lower thermal efficiency of the heater. Hence, several modifications are suggested and applied to improve the heat transfer coefficient between the absorber plate and air.

This study focuses on solar air heaters and their corresponding mathematical modeling and subsequently on developing a program that could be used as a tool to design and predict the thermal efficiency and the cost effectiveness for three different configurations of solar air heaters. This mathematical modeling incorporates knowledge and able to conduct the following:

i. Calculate the important parameters to predict the thermal efficiency; these parameters are absorber plate temperature, the temperature of the transport fluid inside the duct flow, the output temperature and the overall heat loss coefficient.

ii. Determine the optimum operating parameters with respect to the efficiency and outlet temperature. These parameters are mass flow rate and channel flow depth.

iii. Rank the three chosen type of solar air heaters in order of high efficiency with appropriate outlet temperature.

1.2 Background of the Study

There exist several types of solar air heaters in literature. The single most important characteristic of the thermal behavior of solar air heaters is the depth of flow path of the air usually called flow channel depth. It is because both the pressure drop in the duct as well as forced convective heat transfer coefficient depends on the flow channel depth. The collector performance may be improved by employing higher flow rates but at the cost of additional pumping power, which is the recurring cost to the end user. The end user would like to have this recurring cost at its minimum without significantly affecting the collector performance.

1.3 Problem Statement

Although solar air heater has vast potential, it has not received much attention like the solar liquid collectors (Karim and Hawlader, 2004). Air type solar collectors have two problems, low thermal capacity of air and low absorber to air heat transfer coefficient, at the same time the most essential parameter of solar air collector design is the heat transfer coefficient between the absorber and the flowing air since the collector efficiency is strongly affected by this parameter, which in turn is dependent on collector type and operating conditions. Thus different modifications have been suggested and applied to improve the heat transfer coefficient between the absorber plate and the air and several designs are discussed. However, the importance of having an optimum flow channel depth, length and mass flow rate in solar air heaters has not been much identified and studied.

Duffie and Beckman (1991) stated that “The design of a solar collector is concerned with obtaining minimum cost energy. Thus, it is desirable to design a collector with efficiency lower than is technologically possible if the cost is significantly reduced. In any event, it is necessary to predict the thermal efficiency". Therefore the prediction of thermal efficiency of solar collector is important and improves the design.

The main objective of this study is to develop a design program that can reproduce the performance of the flat-plate solar collectors. At the development level the design program can replace physical experimental tests with numerical tests. This program is developed so that detailed information can be specified to allow solar engineers to investigate the impact of design changes on the collector performance.

1.4 Objectives

The objectives of this study are as follows:

- To perform simulation of flat plate solar air heater to determine the thermal efficiency and outlet air temperature.
- To investigate a double pass solar air heater and comparison with single pass with one and two glass covers.
- To investigate thermal performance with respect to changes of ambient and design parameters.

1.5 Scope

In order to achieve the objectives above, the following will be considered:

- To perform literature survey.
- Assume air as the working fluid and taking it as an ideal gas with constant properties.
- Consider steady state conditions
- The study will be performed by simulation only.

1.6 Significance of the Study

The program which has been developed is useful for collector design and for detailed understanding of how collectors function. The program is also useful for design problems in which the impacts of one or more parameters need to be investigated.

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